Section 2.2

Contents of the Tycho Catalogue

2.2. Contents of the Tycho Catalogue

Overview of the Tycho Catalogue: The Tycho Catalogue provides astrometry (positions, parallaxes and proper motions) and two-colour photometry (in B_T and V_T) for more than one million stars brighter than $V_T = 11.5$ mag. The median precision (standard error) is 25 mas in position and 0.10 mag in the $B_T - V_T$ colour index. These values apply at the median magnitude $V_T = 10.5$ mag for stars of median colour index $B_T - V_T \simeq 0.7$ mag. The Tycho Catalogue contains 1 058 332 entries: comprising 1 052 031 entries (stars) observed by Tycho, supplemented by the 6301 entries from the Hipparcos Catalogue and Part C of the Double and Multiple Systems Annex that were not observed by Tycho. The Tycho Catalogue contains roughly 40 000 stars brighter than $V_T = 9$ mag which are not contained in the Hipparcos Catalogue. For these stars the median precision is 7 mas in position, parallax and annual proper motion and 0.019 mag in $B_T - V_T$. Double stars with separations larger than 2 arcsec and with moderate magnitude difference are usually resolved.

The Tycho Catalogue, and its associated Tycho Epoch Photometry Annex, is strictly an observational catalogue. It contains data derived exclusively from the Hipparcos satellite's star mapper observations, with the exception of certain cross-identifications.

The reduced data comprise two parts. The main catalogue (the Tycho Catalogue, or TYC, described in this section) contains the astrometric and summary photometric data for each star. The Tycho Epoch Photometry Annex (described in Section 2.6) contains 'epoch photometry' (photometry at each epoch of observation) for a subset of stars observed with sufficiently high signal-to-noise ratio. In structure, the Tycho Catalogue and its Epoch Photometry Annex resemble the corresponding machine-readable parts of the Hipparcos Catalogue and associated Epoch Photometry Annex.

Solar system objects observed as part of the Tycho experiment are contained within the general annex of solar system observations (see Section 2.7).

Tycho Catalogue Completeness: Some Hipparcos Catalogue stars were not observable by the star mapper. The dynamic range of the star mapper detector resulted in non-linearity at the brightest magnitudes (Sirius was not observable). The faintest Hipparcos Catalogue stars fell below the detection threshold of the star mapper detectors. Stars in very dense clusters and other dense fields could not be observed by Tycho, thus leaving the resulting Tycho Catalogue incomplete in such regions (see, for example, entries flagged 'R' in Field T42). Section 1.1.1 gives further details of the relationship between the Tycho and Hipparcos Catalogues and entries.

All 6301 single star entries and double and multiple star components contained within the Hipparcos Catalogue but not observed by Tycho have nevertheless been included in the Tycho Catalogue for completeness, and assigned a corresponding TYC number. In these cases (flag 'H' in Field T42), the truncated astrometric and photometric descriptor taken from the Hipparcos Catalogue (Fields H3–5) has been included in the Tycho Catalogue at the appropriate location (Fields T3–5). The position of the entry taken from the Hipparcos Catalogue (Fields H8–9) is also included in Fields T8–9 to assist cross-identification between the catalogues.

Among the 120 000 stars in the PPM catalogue brighter than 9.0 mag, about 120 are not contained in the Tycho Catalogue (see Chapter 17, Volume 4 for details).

The following table gives the number of stars in TYC and the number of TYC stars not included in HIP, along with the corresponding median standard errors for stars within the given intervals of V_T magnitude (the column 'All' also including entries for which V_T is not available). Systematic errors in astrometry are less than 1 mas and 1 mas/yr, although the external standard errors (the true accuracies) may be up to 50 per cent larger than the quoted standard errors for faint stars. In photometry, systematic errors may reach the level of the quoted standard errors for faint stars. The photometry for about 20 000 stars is considered to be uncertain, for example when the standard errors are larger than 0.3 mag.

Interval of V_T	<6.0	6–7.0	7–8.0	8–9.0	9–10.0	10–11.0	>11.0	All	<9.0
Median V_T, mag	5.38	6.63	7.62	8.62	9.61	10.58	11.19	10.47	8.33
N (TYC)	4553	9550	27750	78029	211107	515029	205934	1052031	119882
N (not in HIP)	4	55	3485	36511	182773	506720	205275	934901	40055
Median standard errors in astrometry (mas):									
Position (J1991.25)	1.8	2.6	4.0	6.7	12.9	27.2	39.2	24.6	5.6
Parallax	2.5	3.6	5.3	8.6	16.4	34.3	49.6	31.2	7.2
Proper motion/yr	2.3	3.3	5.0	8.3	16.0	33.5	48.6	30.2	7.0
Median standard errors in photometry (mag):									
B_T	0.003	0.006	0.010	0.018	0.036	0.084	0.128	0.074	0.014
V_T	0.003	0.005	0.008	0.014	0.027	0.064	0.122	0.057	0.012
$B_T - V_T$	0.005	0.008	0.014	0.024	0.049	0.117	0.200	0.104	0.019
$B - V$	0.004	0.007	0.012	0.020	0.041	0.098	0.171	0.087	0.017

Tycho Photometry: Tycho photometry was obtained in two colour bands, B_T and V_T, closely corresponding to B and V in the Johnson UBV system. The Tycho colour index, written $B_T - V_T$ or $(B-V)_T$, is not explicitly given, but may be simply derived from the difference of the published magnitudes. Approximate values of the Johnson V magnitude (Field T5) and colour index $B - V$ (Field T37) are also provided, derived by the transformations in Section 1.3, Appendix 4. Because it is a strict observable, and unaffected by the uncertainties inherent in such a transformation, the Tycho colour index rather than the derived Johnson colour index is recommended for use whenever appropriate.

A simple linear transformation from the Tycho B_T, V_T magnitudes to B, V magnitudes in the Johnson photometric system is:

$$V \simeq V_T - 0.090\,(B_T - V_T) \qquad [2.2.1]$$

$$B - V \simeq 0.850\,(B_T - V_T) \qquad [2.2.2]$$

In the interval $-0.2 < B_T - V_T < 1.8$ mag the systematic errors of this simple transformation do not exceed 0.015 mag for V and 0.05 mag for $B - V$ for unreddened main-sequence stars.

Proximity Flag: In analogy with the Hipparcos Catalogue, Field T2 provides a 'proximity flag' giving a coarse indication of the presence of nearby objects (within 10 arcsec). These may be separate Tycho Catalogue entries, or separate Hipparcos Catalogue entries (or components). Further information on nearby objects can be derived from an examination of the relevant Hipparcos or Tycho Catalogue entries, or from Field T49 indicating unresolved duplicity.

Reference Stars: A distinct flag, Field T10, indicates whether the Tycho Catalogue entry is considered as a 'recommended' astrometric reference star. This flag is assigned to classification of the entry as an astrometric reference star since there are several considerations, aside from (possible) duplicity, which may disqualify the object from being classified as a Tycho Catalogue astrometric reference star. Further details are given under Field T10. Hipparcos Catalogue objects not observed by Tycho (i.e. where Field T42 contains 'H') are flagged as dubious Tycho astrometric reference stars even though the object could be a well-behaved, single object within the Hipparcos Catalogue. This distinction has been preserved in order to maintain the consistency of the Tycho Catalogue as an independent observational catalogue.

Most of the Tycho Catalogue magnitudes have sufficient accuracy for calibration of magnitudes derived from photographic survey plates in colour bands near to B or V. Selection according to the criteria adopted under Field T34 results in the availability of about 520 000 Tycho photometric reference stars suitable for such purposes.

Transits, Detections, Measurements: In the terminology of the Hipparcos Catalogue, a star 'transit' is defined as a crossing of the star across the main modulating grid (2688 slits covering a field of view of approximately $0\overset{\circ}{.}9 \times 0\overset{\circ}{.}9$). In the terminology of the Tycho Catalogue, a 'transit' refers to the crossing of the star across a star mapper slit system (either of a set of four vertical or inclined slits of 40 arcmin length, located at the edge of the main field of view, and used primarily for the satellite real-time attitude determination). Such a transit is defined irrespective of whether or not such a crossing yields 'useful' astrometric and/or photometric information. The transit yields useful astrometric and/or photometric information when the star is not too faint, when the background was below a certain limit, when an accurate attitude determination was available, and when the observations were not perturbed by nearby bright stars. Details of the measurements and reductions are given in Volumes 2 and 4.

All relevant transits related to a given star have been combined to provide the astrometric data and the summary photometric data contained in the main Tycho Catalogue, and individual transit records (providing 'epoch photometry') are contained in the Tycho Epoch Photometry Annex. The summary photometric data provide median magnitudes for bright stars and 'de-censored mean magnitudes' for fainter stars, and a set of parameters and flags giving an overview of the variability. The Tycho Epoch Photometry Annex includes details of each transit including background, observation epoch, and related quantities and flags.

In practice, the detection process giving a signal amplitude and a transit time was carried out on a signal where the photon counts in the B_T and V_T channels had been added, forming the so-called T channel. The term 'detected transit' is used to refer to a transit containing a significant signal belonging to the relevant star, and this signal itself is called a detection. When a signal was detected above a signal-to-noise ratio of 1.5 in the T channel an estimation (or measurement) of the signal amplitude was carried out in the B_T and V_T channels separately whenever possible. If no such measurement was available, a flag in the first two bits of Field TT13 (see Table 2.6.2) indicates that the magnitude could not be measured in one or other of the separate channels.

Valid and Invalid Transits for Photometry: Transits were used for Tycho (mean value) photometry irrespective of whether or not the object was actually detected in the predicted 'transit interval' of a few arcsec length for the corresponding slit group—the condition for using the transit being simply that the relevant data interval was considered to be 'valid'. Such a transit interval could contain several detections (either real detections due to the predicted star or to another star, or false detections due simply to photon noise) or it could contain no detection at all.

Certain transit intervals were considered as 'invalid', and subsequently excluded from use in Tycho photometry, for a variety of reasons:

(a) if the satellite attitude was poorly known, or if (attitude-control) jet firings were affecting the satellite attitude estimation at the moment of the observations;
(b) if the detector background was high, for example as a result of a passage of the satellite through the van Allen radiation belts—a higher background was acceptable for astrometry than for photometry;
(c) because the star crossed the star mapper slit system too close to the end of the slit, or to the 90° angle of the inclined slits—in such cases, attitude uncertainties may have made it infeasible to distinguish between 'uncaptured' transits, and transits where the signal was below the detectability threshold.

Non-Detections and De-Censored Magnitudes: A valid transit interval was classified as 'non-detected' or 'censored' if it contained no detection, in the T channel, close enough to the predicted transit time for the relevant star. The criterion for rejection was that all residuals of detections in the astrometric adjustment of the transit interval were larger than given limits.

Limits used in astrometry for the rejection of detections were $|\Delta u| > 1.0$ arcsec or $|\Delta u| > 3\sigma_u$, where Δu is the difference between the observed and computed transit times (converted to an angular distance using the instantaneous satellite scan speed across the slit group), and σ_u is the standard error of Δu. A single limit was used in the de-censoring analysis, $|\Delta u| > 0.6$ arcsec. Since transit detection was based on preliminary predicted transit times, which were sometimes in error by a large amount, the real transit occasionally occurred outside the predicted transit interval. Such detected transits were not assigned to the correct star and were thus lost, even when the improved transit times were introduced at a later stage. As a consequence, non-detections were occasionally associated even with bright stars. This problem was accommodated within the mathematical model for the de-censoring analysis by assuming that there was a probability of 6 per cent that a predicted Tycho star transit resulted in a non-detection even for a bright star. This is referred to as the assumption of 6 per cent 'spurious non-detections', and users of the Tycho epoch photometry should be aware of this deficiency. Photometric standard star observations were used for checking the validity of the de-censoring analysis and for correcting final small biases, as described in further detail in Volume 4, Chapter 9.

The use of non-detected transits has two reasons. First, because detectability depends on the signal-to-noise ratio of a given transit, mean or median magnitudes have not simply been constructed from the detected transits—rather, a 'de-censored mean magnitude' in B_T and V_T was constructed, using model-based inferred magnitudes in place of transits which were either not detected in the T-channel, or detected but not measured in the B_T or V_T channels. All valid transits were thus taken into account, whether detected or not (see Volume 4 for details). Second, non-detected transits may be relevant in variability studies, where it may be important to identify whether a photometric data point is absent because the object's magnitude fell below the threshold at that epoch, or simply because no data were acquired at that epoch. But a non-detection is not always

an indication that the star was too faint to be detected due to the 6 per cent spurious non-detections described above.

For bright stars with $B_T \leq 8.5$ mag and $V_T \leq 8.0$ mag a median magnitude was derived from the measured signal in the B_T and V_T channels respectively. This median magnitude is equivalent, within 0.005 mag, to a de-censored mean magnitude because bright stars resulted in very few non-detections. The median magnitude was adopted for bright stars since the median could also be constructed for variable stars, while the de-censoring analysis was based on the assumption that the star is constant.

Parasites: Some transits have been flagged as disturbed by a 'parasite', i.e. a fairly bright star which was close in transit time to that of the star considered, according to calculations based on the stars in the Tycho Input Catalogue Revision, described in further detail in Volume 4. Such transits were rejected in the astrometric adjustment, and (partly) in the de-censoring analysis since these analyses were sensitive to outlying observations. They are however included in the Tycho Epoch Photometry Annex (flagged in bit 2 of Field TT13, see Table 2.6.2) if none of the conditions (a–c) discussed under 'Valid and Invalid Transits for Photometry' also caused a rejection in the astrometric adjustment. The flag was not used in the construction of median magnitudes since the median is only weakly affected by outliers, and since such transits in fact often do not suffer from any significant photometric disturbance.

Number of Transits: The number of valid transits for a given TYC entry, including the non-detections, is denoted by $N_{\rm transits}$. The Tycho Epoch Photometry Annex contains $N_{\rm transits}$ transits for the selected stars, and the number is given in Field TH4 of the corresponding header record (see Section 2.6).

The final astrometric and photometric results for each star have typically been constructed from different numbers of star transits in each case—individual transits having been used, or rejected, for the final catalogue for a variety of reasons. The number of transits used in the *astrometric* adjustment, $N_{\rm astrom}$, is given in Field T29 of the main Tycho Catalogue. It excludes non-detections and detections affected by parasites.

The number of transits used in Tycho mean value photometry, $N_{\rm photom}$, is given in Field T43 of the main Tycho Catalogue. $N_{\rm astrom}$ and $N_{\rm photom}$ are about 25 per cent less than $N_{\rm transits}$. The number of valid transits was slightly lower for photometry than for astrometry because a higher background was acceptable in astrometry. The process of photometric de-censoring used both detections which were unaffected by parasites, and the non-detections. Therefore, for stars brighter than $V_T \simeq 10$ mag with few non-detections the ratio $N_{\rm photom}/N_{\rm astrom} \simeq 0.80$, while for fainter stars with many non-detections the ratio may be as large as 1.5. For median magnitudes only detections were used, including those affected by parasites, since these were too few to have any significant effect on the median.

Format of the Tycho Catalogue

Unlike the main Hipparcos Catalogue, the Tycho Catalogue and the Tycho Epoch Photometry Annex are not made available in printed form, but only as a machine-readable version.

The Tycho Catalogue format is largely identical to that of the Hipparcos Catalogue up to and including Field H39/T39. This approach is intended to facilitate use of both catalogues. Thereafter, additional Tycho Catalogue fields are included with astrometric and photometric information and cross-identifications to other catalogues. Flags indicate variable stars, detected duplicity or multiplicity, or notes.

Entries of the Tycho Catalogue are given in the sequence of the hierarchical TYC1–3 identifier (Field T1), i.e. corresponding to organisation according to the GSC (Guide Star Catalog) region number (and not in sequence of right ascension).

The same conventions and units are adopted for the Tycho Catalogue as for the main Hipparcos Catalogue. Thus, definitive values of right ascension and declination are expressed in degrees and decimals of a degree, while all other astrometric parameters, and errors, are expressed in milliarcsec, even though some digits may not be significant. The catalogue epoch is J1991.25, and positions and errors are given for that epoch. Astrometric correlations are also provided. All parameters are expressed within the reference system ICRS (see Section 1.2.2). Positions are also provided in conventional sexagesimal units, with truncated precision. Similar approaches have also been adopted for the categorisation of variability data.

Double and multiple star detection differs significantly between the Hipparcos main mission and Tycho, and fields dedicated to summary double and multiple star data in the main Hipparcos Catalogue are accordingly absent in the Tycho Catalogue.

Fields T0–2: Tycho Identifier/Proximity Flag

Field T0: The machine-readable (main) Hipparcos and Tycho Catalogues include a character indicating whether the associated record is derived from Hipparcos (H) or Tycho (T) data. Field H1/T1 then provides the Hipparcos Catalogue number (HIP) or the Tycho Catalogue identifier (TYC) accordingly, with the interpretation of subsequent fields being, in part, catalogue dependent (see Tables 2.1.1 and 2.2.1).

Field T1: TYC identifier

The designation of the object within the Tycho Catalogue uses the Guide Star Catalog (GSC) numbering system (a region number, designated here TYC1; and a number within the region, designated here TYC2) followed by a Tycho Catalogue specific component number (TYC3). As well as giving a cross-identification to an important star catalogue, this designation system has the advantage of giving a rough position indication. For objects contained in the GSC, TYC1 and TYC2 are identical to the identifiers defined by the GSC numbering system.

In the few cases where no corresponding GSC object exists close to the Tycho Catalogue object, values of TYC1 and TYC2 consistent with the GSC numbering system were created with the assistance of the Guide Star Catalog team. The component number (TYC3) gave necessary flexibility for addition of objects during the Tycho Catalogue production discovered close to the GSC object designated by the values of TYC1 and TYC2. The TYC3 numbers have been assigned starting with 1 and increasing with the V_T magnitude. Components with TYC3 > 1 are always located within a distance of 15 arcsec from the corresponding star with TYC3 = 1.

The recommended TYC designation contains a hyphen between the TYC numbers, e.g. for the first star in the Tycho Catalogue the designation is 'TYC 1–13–1', corresponding to 'GSC 1–13'. The TYC identifier of the first entry in the catalogue is ' 1   13 1'.

The maximum value for each of the TYC numbers is as follows: TYC1 = 9537; TYC2 = 12119; TYC3 = 4. The number of entries with each of the occurring TYC3 numbers is as follows: 1 = 1 051 966; 2 = 6334; 3 = 31; 4 = 1. The entry with 4 TYC3 components is TYC 1327–606–1 to –4 = HIP 30075 ABCD of which the components C and D were only measured by Hipparcos.

All stars contained within the Hipparcos Catalogue but not observed by Tycho have also been included in the Tycho Catalogue for completeness (see Field T42) and assigned a corresponding TYC number.

Field H31, which appears as the first column of the right-hand page of the printed Hipparcos Catalogue, contains the Hipparcos Catalogue (HIP/HIC) identifier. This is retained for the Tycho Catalogue, so that Fields T31 and T51 (which gives the Hipparcos component identifier, if any) provide the links between the Hipparcos and Tycho Catalogues.

Field T2: Proximity flag

This field provides a coarse indication of the presence of nearby objects. If non-blank, it indicates that there is one or more distinct Hipparcos Catalogue entries (or distinct components of the system if double or multiple), or one or more distinct Tycho Catalogue entries, in either case irrespective of magnitude, within 10 arcsec of the position given in Fields T8–9. The term 'distinct' means simply that a proximity flag is not assigned to a Tycho Catalogue entry cross-identified with the same (single) star contained within the Hipparcos Catalogue.

The flag is assigned according to the following hierarchy (i.e. if 'H' and 'T' both apply, 'H' is adopted):

H : there is one or more distinct Hipparcos Catalogue entries, or one or more distinct components of the relevant Hipparcos Catalogue entry, within 10 arcsec of the position given in Fields T8–9. This includes the cases where two Hipparcos components are merged into one Tycho entry (see also Field T51);

T : there is one or more additional Tycho Catalogue entries within 10 arcsec of the position given in Fields T8–9.

The number of entries in each of these categories is as follows: H = 12 812; T = 5851.

Fields T3–7: Descriptor

Fields T3–4 provide an approximation to the position given in Fields T8–9, and are included as a convenient way of object identification. Fields T5–7 provide an approximate but rather homogeneous indication of the V magnitude in the Johnson UBV system, along with a source flag.

Fields T3–4: Positional identifier: truncated coordinates (epoch J1991.25, ICRS)

The approximate right ascension and declination are given in conventional sexagesimal units with truncated precision, for epoch J1991.25, and within the reference system ICRS. Fields T3–4 are rounded values of the positions given in Fields T8–9, and are included as a convenient way of object identification. Since the identifier is strictly constructed from the Tycho position, identifiers for entries contained in both the Hipparcos and Tycho Catalogues will not necessarily be identical.

Field T5: V magnitude

The V magnitude is given mainly for identification purposes (see Field T7). Normally this V magnitude is in the Johnson UBV photometric system, although this is not the case for some entries as specified in Field T7.

The field is blank for 3217 entries, all faint ($Hp > 10.9$ mag) Hipparcos double star components.

Although Tycho observations give magnitudes in the photometric bands referred to as B_T and V_T, the magnitude identifier has been transformed from the available B_T and V_T data to a magnitude in the V band, for consistency with the information given in the Hipparcos Catalogue, using the transformations defined in Section 1.3, Appendix 4. Magnitudes are given to two decimal places, with typical systematic errors of about 0.01 mag, although much larger systematic errors are expected especially for red stars, i.e. with $B - V > 1.5$ mag.

The standard error is usually $\simeq 1.1\sigma_{V_T}$, but may be calculated more accurately using Equation 1.3.21. The magnitude is very uncertain if Field T57 is not blank, in particular if it contains 'M'.

Field T6: This field (coarse variability flag for HIP) is blank for Tycho

Field T7: Source of magnitude given in Field T5

The V magnitude, considered primarily as a magnitude 'identifier' (although with astrophysical relevance) has usually been derived from the available B_T and V_T data, as described under Field T5. Otherwise, if non-blank, the field has the following meaning:

- B : no V_T magnitude is available, therefore the B_T value was adopted;
- D : derived from approximate B_T and V_T magnitudes, corresponding to flag 'D' in Field T36;
- T : only an approximate V_T magnitude has been derived, as indicated by flag 'T' in Field T36; in these cases, the V magnitude given in Field T5 is simply the approximate V_T magnitude given in Field T34;
- V : no B_T magnitude is available, therefore the V_T value was adopted;

The number of entries in each of these categories is as follows: B = 79; D = 3314; T = 1333; V = 173.

Fields T8–30: Astrometric Data

The data in Fields T8–30 are the same in both format and meaning in the Tycho Catalogue as in the Hipparcos Catalogue, i.e. position, proper motion, parallax, astrometric standard errors and correlations, and solution flags. Positions are expressed in degrees. Annual proper motion components, trigonometric parallaxes, and all astrometric errors (including those of positions) are expressed in milliarcsec. Angular measures are along a great circle, including the factor of $\cos\delta$ for positional error in right ascension, for proper motion in right ascension, and for proper motion error in right ascension. If parameters such as the proper motion or parallax were not calculated (e.g. for a close companion having too few observations) the corresponding field will be blank.

The right ascension and declination are referred to the catalogue epoch, J1991.25, as described in Section 1.2.6. Corresponding standard errors, also at the catalogue epoch, are given in Fields T14–18. Positions and proper motions are referred to ICRS, as described in Section 1.2.2. The astrometric positions and their errors can be propagated to the standard epoch J2000.0, or to any other epoch, within the ICRS frame, by the methods described in Section 1.2.8. [Since for many Tycho Catalogue entries the proper motion will have a standard error larger than the expected proper motion itself ($\mu \simeq 20$ mas/yr for a star of spectral type F5 and $V = 11$ mag), a more accurate position for faint stars at a different epoch may often be predicted by assuming a zero proper motion.]

Fields T8–9: Equatorial coordinates (epoch J1991.25, ICRS)

The right ascension, α, and declination, δ, are expressed in degrees for the catalogue epoch J1991.25, and with respect to the reference system ICRS.

ICRS is consistent with the conventional coordinate system at J2000.0, previously realised by the FK5 Catalogue.

The source of astrometric data is detailed in Field T42. If only the position is given (i.e. if Field T42 is non-blank), Fields T11–13 and T16–28 will be blank, and sometimes also other fields. Formal positional standard errors are still given in Fields T14–15 if Field T42 = ‘P’ or ‘R’, although they will be less reliable than the standard errors corresponding to a full astrometric solution. If Field T42 = ‘H’, the position given in Fields T8–9 is the position taken directly from the Hipparcos Catalogue.

Field T10: Reference flag for the astrometric parameters

This flag indicates that the astrometric parameters in Fields T8–30 refer to:

␣ : a recommended astrometric reference star, having good Tycho astrometric quality, and not recognised as double;

X : a dubious astrometric reference star in the context of the Tycho Catalogue.

A star is flagged as a dubious astrometric reference star either because the quality flag in Field T40 is $Q \geq 6$, or because Fields T2 or T42 are non-blank, or because Field T49 = ‘D’ or ‘S’ indicating possible duplicity, or because Field T57 = ‘J’, ‘K’ or ‘L’ indicating dubious astrometry. The case where Field T42 contains ‘H’ (Hipparcos entry not observed by Tycho) is systematically classified as ‘dubious’ within the context of the Tycho Catalogue, even though it could be a well-behaved, single object within the Hipparcos Catalogue.

The number of entries in each of these categories is as follows: ␣ = 886 621; X = 171 711. The catalogue thus contains nearly 900 000 recommended astrometric reference stars.

Field T11: Trigonometric parallax

The trigonometric parallax, π, is expressed in units of milliarcsec. The estimated parallax is given for every star, even if it appears to be insignificant or negative (which may arise when the true parallax is smaller than its error).

Fields T12–13: Proper motion components (epoch J1991.25, ICRS)

The proper motion components, $\mu_{\alpha*} = \mu_\alpha \cos\delta$ and μ_δ, are expressed in milliarcsec per Julian year (mas/yr), and are given with respect to the reference system ICRS.

Fields T14–15: Standard errors of the equatorial coordinates (epoch J1991.25)

The standard errors of the right ascension, $\sigma_{\alpha*} = \sigma_\alpha \cos\delta$, and declination, σ_δ, are given at the catalogue epoch, J1991.25, and are expressed in milliarcsec.

Field T16: Standard error of the trigonometric parallax

The standard error of the trigonometric parallax, σ_π, is given in milliarcsec.

Fields T17–18: Standard errors of the proper motion components

The standard errors of the proper motion components, $\sigma_{\mu_{\alpha*}} = \sigma_{\mu_\alpha \cos\delta}$ and σ_{μ_δ}, are expressed in milliarcsec per Julian year (mas/yr).

Fields T19–28: Correlation coefficients

The correlation coefficients (see Section 1.2.7) are given as (real) numerical values in the following order:

T19 = $\rho^{\delta}_{\alpha*}$
T20 = $\rho^{\pi}_{\alpha*}$
T21 = ρ^{π}_{δ}
T22 = $\rho^{\mu_{\alpha*}}_{\alpha*}$
T23 = $\rho^{\mu_{\alpha*}}_{\delta}$
T24 = $\rho^{\mu_{\alpha*}}_{\pi}$
T25 = $\rho^{\mu_{\delta}}_{\alpha*}$
T26 = $\rho^{\mu_{\delta}}_{\delta}$
T27 = $\rho^{\mu_{\delta}}_{\pi}$
T28 = $\rho^{\mu_{\delta}}_{\mu_{\alpha*}}$

corresponding to the sequence illustrated in the following table:

	$\alpha*$	δ	π	$\mu_{\alpha*}$	μ_δ
$\alpha*$	–	T19	T20	T22	T25
δ	T19	–	T21	T23	T26
π	T20	T21	–	T24	T27
$\mu_{\alpha*}$	T22	T23	T24	–	T28
μ_δ	T25	T26	T27	T28	–

The use of the asterisk notation, $\mu_{\alpha *} = \mu_\alpha \cos\delta$, etc., is not really required in the correlations, since the correlation coefficient is the same between (say) α and δ, as between $\alpha\cos\delta$ and δ. Nevertheless, it has been retained for uniformity.

Field T29: The number of transits retained in the astrometric adjustment, $N_{\rm astrom}$

The number of transits retained in the astrometric adjustment corresponds to those remaining after the rejection of outliers, as defined in the introduction to the present section.

While Field H29 gives the fraction of rejected observations for the main Hipparcos Catalogue, the number of rejected transits is of no value in assessing a goodness-of-fit for objects in the Tycho Catalogue—it is usually of the order of 50 per cent, due to the definition of the identified transits.

Field T30: Goodness-of-fit parameter, F2

This number indicates the goodness-of-fit of the solution to the accepted data. For good fits F2 should approximately follow a normal distribution with zero mean value and unit standard deviation. F2 values exceeding +2.5 to +3 thus indicate a bad fit to the data. Its construction and interpretation are explained further under Field H30 (Section 2.1). The F2 value was, however, not used for generating the astrometric quality flag in Field T40, where classification measures derived from other aspects of the data reduction were found to be more informative.

The resulting F2 distribution is close to normal for single stars, i.e. for the recommended astrometric reference stars with no flag set in Field T10. The mean of the distribution is $\simeq 0.73$ and the standard deviation 1.20; the former arising from the fact that the unit weight error, $(\chi^2/\nu)^{1/2}$, is about 1.04. The unit weight error is included as a factor in the astrometric standard errors (see Volume 4, Equation 11.2) given in Fields T14–18 (but not in the corresponding errors for Hipparcos, Fields H14-18). The effect of this factor is discussed in Volume 4, Section 18.1. The unit weight error may be calculated for a star if F2 is given, as:

$$\text{unit weight error} = \left[\left(\frac{2}{9\nu}\right)^{1/2} \text{F2} + 1 - \frac{2}{9\nu}\right]^{\frac{3}{2}}$$

where $\nu = N_{\rm astrom} - 5$.

Field T31: Hipparcos Catalogue number, as Field H31

The Hipparcos Catalogue number is given for 123 431 entries (there are 117 955 different HIP numbers, in agreement with the number of entries in the Hipparcos Catalogue with an astrometric solution).

Field H1 gives further details of the HIP identifier.

The number of Tycho Catalogue entries with cross-identification to the Hipparcos Catalogue is larger than the number of entries in the main Hipparcos Catalogue since the corresponding HIP number is also given, where appropriate, for Tycho Catalogue entries corresponding to components contained in the Hipparcos Catalogue Double and Multiple Systems Annex (see also Field T51). The associated CCDM component identifier, if relevant, is given in Field T51 for 18 687 entries.

Fields T32–39: Photometric Data

These fields generally retain the same structure as the corresponding fields of the Hipparcos Catalogue. Fields T32–35 contain B_T and V_T magnitudes, and associated standard errors, precisely the same as the values given under Fields H32–35. The flag in Field T36 specifies how these 'mean' magnitudes have been obtained, i.e. as 'de-censored mean', as 'median' or 'approximate'.

For most stars (96 per cent) de-censored mean magnitudes are given because of the 'censoring' (non-detection) of faint transits in the case of Tycho observations, as described in the introduction (a simple median or mean value of the detected amplitudes would result in a biased estimate of the star's magnitude). Thus Fields T32 and T34 provide 'de-censored mean magnitudes' if the flag 'N' is given in Field T36. These magnitudes are derived from an analysis taking specific account of individual transits likely to have fallen below the detectability threshold for a subset of the observations. Estimates of the standard errors, and a description of the notation $\sigma^-_{B_T}$ and $\sigma^-_{V_T}$, are given in Section 1.3.6.

For bright stars median magnitudes B_T, V_T were computed with the errors obtained from the 15th and the 85th percentile of the distribution. (Note that for the *Hp* photometry included in the main Hipparcos Catalogue, *median* magnitudes were derived from all observations, and the error on the median was computed from the 35th and 65th percentiles of the distribution—as described in Section 1.3.6.)

Approximately 10 000 photometric standards were effectively used in the Tycho photometric calibration, making use of *a priori* B_T and V_T magnitudes derived from ground-based observations, appropriately transformed to magnitudes in the Tycho photometric system. These *a priori* values are considered of limited relevance for the Tycho Catalogue, and are not provided.

The magnitudes, colour indices and standard errors are given as obtained by computation from the individual photometric observations, thus accepting sometimes rather unreasonable results for faint stars. The following limitation of intervals has however been carried out in Fields T32–35, T37–38, and T45–46:

- for Fields T32–35: magnitudes fainter than 15.0 mag in B_T and V_T derived by de-censoring and their standard errors were replaced by blanks. If both B_T and V_T were then missing a V_T magnitude of 15.0 mag was adopted. The reason for this limitation is that the distribution of de-censored magnitudes fainter than 15.0 mag clearly indicated that these magnitudes were incorrect, probably arising from stellar variability or photon noise. Although highly uncertain, it was considered more appropriate to assign such a magnitude—in order to have been detected by Tycho the star must, at least during some interval, have been brighter than the detection limit of $V_T \simeq 12$ mag;
- for Field T37–38: the $B - V$ colour index has been omitted if the value was outside the interval $-2.0 < B - V < +5.0$ mag, leaving blanks in these fields;
- for Fields T45–46: magnitudes of the percentiles in Field T46 fainter than 15.0 mag were replaced by blank. This never happened in Field T45.

Fields T32–33: The B_T mean magnitude, $\langle B_T \rangle$, and standard error $\sigma^-_{B_T}$

The number of entries with standard errors of B_T in given ranges is as follows: < 0.1 = 681 190; 0.1 – 0.3 = 352 552; > 0.3 = 16 783. See also Fields T34–35.

Fields T34–35: The V_T mean magnitude, $\langle V_T \rangle$, and standard error $\sigma^-_{V_T}$

The number of entries with standard errors of V_T in given ranges is as follows: < 0.1 = 840 854; 0.1 – 0.3 = 206 435; > 0.3 = 4634.

The B_T and V_T magnitudes are considered to be very uncertain if Field T57 is not blank, especially if it contains 'M'. The choice of suitable photometric reference stars from the Tycho Catalogue for B_T and V_T will depend on the application, but should generally require that Field T36 = 'M' or 'N', and Fields T2 = T47 = T48 = T57 = ␣, and Field T49 is not 'D' or 'S'. Additional criteria on σ_{B_T} and σ_{V_T} may be defined by the user. If this latter requirement is $\sigma < 0.1$ mag, for example, a total of 520 631 Tycho photometric reference stars are available for calibration of photographic survey plates.

Field T36: Source of photometric data

The source flag has the following meaning:

D : approximate B_T, V_T magnitudes obtained during astrometric processing of resolved double stars, based on photometric signal amplitudes; no percentiles are given;

M : the B_T, V_T data are median values, rather than de-censored mean values (mainly relevant for bright stars with $B_T \leq 8.5$ mag and $V_T \leq 8.0$ mag);

N : the B_T, V_T data are de-censored mean values derived from the de-censoring analysis from the (normal) photometric processing for faint stars;

T : an approximate magnitude is given in Field T34 for V_T, and Field T32 for B_T is blank. The magnitude estimate was obtained from a combination of B_T and V_T observations during the Tycho Input Catalogue Revision (see Field T43) or the astrometric processing. These magnitudes are systematically too bright, by up to 1 mag for stars of $T = 11$ mag, and epoch photometry or percentiles can sometimes not be given. In these cases, the V magnitude given in Field T5 and flagged in Field T7 is simply this approximate V_T magnitude;

␣ : the Hipparcos stars (Field T42 = 'H').

The number of entries in each of these categories is as follows: D = 3314; M = 29 524; N = 1 017 860; T = 1333; ␣ = 6301.

Fields T37–38: The $B - V$ colour index, and standard error

These values give an indication of the Johnson $B - V$ colour index and standard error. The value of $B - V$ is derived strictly from Fields T32 and T34 if both these fields are non-blank (i.e. from $B_T - V_T = \langle B_T \rangle - \langle V_T \rangle$) according to the transformations given in Section 1.3, Appendix 4. If either B_T or V_T are not available, then the field is blank.

Unlike the case for the Hipparcos Catalogue, the colour index in Field T37 is never derived from ground-based data. In those cases where Field H37 contains a better estimate of $B - V$ than that derived from the Tycho data, Fields H37 and T37 will therefore be different. These two fields may also differ because effects of luminosity and reddening have been taken into account in constructing Field H37, but not in Field T37. Because of these limitations, the $B - V$ colour index given in the Tycho Catalogue is therefore only indicative; it is consequently recommended to make use, wherever possible, of the directly observed index $B_T - V_T$ (and correspondingly to use V_T rather than the V magnitude given in Field T5). Standard errors in $B - V$ and $B_T - V_T$ are related approximately by $\sigma_{(B-V)} \simeq 0.85\,\sigma_{(B-V)_T}$ (see Section 1.3.6).

The number of entries with standard errors of $B - V$ in given ranges is as follows: < 0.1 = 592 918; 0.1 – 0.3 = 423 105; > 0.3 = 33 556; ␣ = 8753. The number of entries with standard errors of $B_T - V_T$ in given ranges is as follows: < 0.1 = 504 132; 0.1 – 0.3 = 485 910; > 0.3 = 59 537; ␣ = 8753.

Field T39: blank for Tycho

Tycho-Specific Fields

Fields H40–70 of the Hipparcos Catalogue (which contain certain colour indices, variability data, multiplicity data, and certain flags), are not relevant to the Tycho Catalogue. Fields T40–57 are used for Tycho specific parameters, other flags, and cross-identifications.

Fields T40–42: Astrometry Related

Field T40: Astrometric quality flag, Q

The astrometric quality is defined for the Tycho data according to the following table, where N gives the number of stars in the Tycho Catalogue of each quality class, Q:

Q	$\sigma_{\rm max}$ (mas)	F_S	$\sigma_{\rm obsf}$ (mas)	N	$\sigma_{\rm med}$ (mas)	Astrometric quality
1	< 5	> 5	< 300	23147	2.6	very high
2	$5 - 10$	> 5	< 300	70945	5.5	very high
3	$10 - 25$	> 5	< 300	259695	13	high
4	$25 - 50$	> 5	< 300	430182	26	high
5	$50 - 150$	> 5	< 300	146520	39	medium
6	< 150	> 5	≥ 300	41695	44	perhaps non-single
7	< 150	$3 - 5$	< 300	37821	45	low
8	< 150	$3 - 5$	≥ 300	28949	54	perhaps non-stellar
9	$\equiv 200$	–	–	13077	–	low, ‘R’ in Field T42
␣	–	–	–	6301	–	unassigned, ‘H’ in Field T42
any	–	–	–	1058332	25	all entries

$\sigma_{\rm max}$ is the largest of the five astrometric standard errors for a given star; F_S is the signal-to-noise ratio given in Field T41; $\sigma_{\rm obsf}$ is the formal standard error of the single observation, being a measure of the half-width of the observed star image: $\sigma^2_{\rm obsf} = 0.25(\sigma_x^2 + \sigma_y^2)(N_{\rm astrom} - 5)$, where σ_x and σ_y are the standard errors of the two position components; and $\sigma_{\rm med}$ gives the median standard error of a position coordinate at the catalogue epoch J1991.25 (the errors at the mean epoch of observation of any given star are typically about 5 per cent smaller).

Objects with $Q \leq 8$ in the Tycho Catalogue all have $F_S > 3$, $\sigma_{\rm max} < 150$ mas, $\sigma_{\rm obsf} < 450$ mas, and $N_{\rm astrom} > 30$ (excluding objects for which $N_{\rm astrom} \leq 30$ only has the effect of excluding less than 100 stars of low quality, because the F_S limit is the strongest criterion). Objects with $Q = 9$ have lower astrometric quality, and are included for the sake of their photometric data—these objects are flagged by ‘R’ in Field T42. The goodness-of-fit parameter (Field T30) did not provide additional useful information in defining the astrometric quality. The last line in the table shows that 6301 entries have ‘H’ in Field T42, showing that they are contained in the Hipparcos Catalogue, but were not observed by Tycho.

Field T41: Signal-to-noise ratio of the star image, F_s

This is defined as $F_s = (n_1 - n_2)/\sqrt{n_1 + n_2}$, where n_1 is the number of detections within 0.7 arcsec along scan from the mean position, and n_2 is the number of detections between 0.7 and 1.4 arcsec (which provides a measure of the rate of background detections). In the special but rather common case of a sharp image on a negligible background, $n_1 \sim N_{\rm astrom}$, $n_2 \sim 0$ and $F_s \sim \sqrt{N_{\rm astrom}}$. The field is blank for stars flagged as 'R' in Field T42.

Field T42: Source of astrometric and other data

For the majority of Tycho entries this field is blank, indicating that the astrometric data is derived from the standard data processing. Otherwise, this field has the following meaning:

H : for the Hipparcos stars not observed by Tycho (i.e. a few bright stars, some stars in double and multiple systems, and in clusters and other dense fields, and faint Hipparcos stars below the observability limit of Tycho), this flag indicates that a GSC-type identifier has been created for Field T1, with the astrometric and photometric descriptor, taken from the Hipparcos Catalogue (Fields H3–5, and H8–9), inserted in Fields T3–5, and T8–9: no magnitude is, however, given in Field T5 for Hipparcos components from Part C of the Double and Multiple Systems Annex. The HIP number and the CCDM component identifier are inserted in Fields T31 and T51 respectively;

P : only the position was determined, either because the entry is a component of a double star resolved in Tycho astrometric analysis of suspected doubles, or because incomplete information was acquired for the entry. In these cases, Fields T11–13, and T16–28 are blank;

R : indicates that only an approximate position (with an accuracy of about ±200 mas) derived from the Tycho Input Catalogue Revision is given, because many transits were flagged as potentially disturbed by a parasite (see the introductory remarks to this section). Nevertheless, many of the transits were still considered to have yielded useful photometric information, and they are therefore included in the Tycho Epoch Photometry Annex. The astrometric quality of such an entry (Field T40) is given by $Q = 9$, and Fields T11–13, T16–30, and T41 are blank.

The number of entries in each of these categories is as follows: H = 6301; P = 3509; R = 13 077.

Fields T43–50: Photometry Related

Field T43: The number of transits used in Tycho mean photometry, $N_{\rm photom}$

This number is discussed in the introduction to this section. In the case of median magnitudes, i.e. flag 'M' in Field T36, this is the number of photometrically valid transits, including all detections, even those affected by parasites, but excluding the non-detections. In case of de-censored mean magnitudes, i.e. flag 'N' in Field T36, this is the number of photometrically valid transits, including the non-detections and the detections not affected by parasites. In case of 'D' or 'T' in Field T36 the number is equal to $N_{\rm astrom}$, except for magnitudes from the Tycho Input Catalogue Revision where the field has been set blank.

Field T44: V_T scatter, s

An estimate of the scatter for the Hipparcos Hp photometric data (Field H46) is given by $s = \frac{1}{2}[x(0.85) - x(0.15)]$ (see Section 1.3, Appendix 1). The same definition of the scatter is used for stars with median magnitudes ('M' in Field T36).

For the fainter Tycho observations with de-censored mean magnitudes ('N' in Field T36) where the 85th (fainter) percentile may be undetermined, the scatter in V_T has been defined by $s = V_T(0.50) - V_T(0.15)$, where $V_T(0.50)$ is the de-censored median and $V_T(0.15)$ is the 15th (brighter) percentile. This definition is similar to that used for the Hipparcos main mission photometry.

For Fields T44–46, non-detected transits are accounted for in the de-censoring analysis on the assumption that the star is not variable.

Field T45: V_T magnitude at maximum luminosity

This is given by the 15th percentile of the $N_{\rm photom}$ transits. This quantity is given for entries with 'M' or 'N' in Field T36.

Note that the 5th percentile (rather than the 15th percentile) is given in the Hipparcos Catalogue for the corresponding Hp magnitude at maximum luminosity.

Field T46: V_T magnitude at minimum luminosity

This is given by the 85th percentile of the $N_{\rm photom}$ transits. This quantity is given for entries with 'M' or 'N' in Field T36, except for the faintest stars. The field is blank for about 150 000 stars for which Field T45 is given.

Note that the 95th percentile (rather than the 85th percentile) is given in the Hipparcos Catalogue for the corresponding Hp magnitude at minimum luminosity.

Field T47: Previously known or suspected as variable

The flag indicates that the star is, according to SIMBAD, listed in either the GCVS or the NSV as follows:

G : GCVS, General Catalogue of Variable Stars, 4th edition (P.N. Kholopov *et al.*, Publ. Office 'Nauka', Moscow, 1985–88);

N : NSV, New Catalogue of Suspected Variable Stars (P.N. Kholopov, *et al.*, Publ. Office 'Nauka', Moscow, 1982).

This field has been constructed using the data available from CDS (SIMBAD) as of April 1996.

The astrometric quality of the GCVS and NSV Catalogues is generally rather poor, and the assignment of the flag must therefore be interpreted with appropriate caution. [For example, after completion of the Tycho Catalogue, it was noted that for the variable GQ Ori, TYC 734–1163-1 rather than TYC 734–627–1 had been assigned flag 'G'; the same error is present in the Hipparcos Input Catalogue for HIC 29386.]

The number of entries in each of these categories is as follows: G = 4068; N = 2624.

Field T48: Flag indicating variability of the Tycho measurements

The flag has the following meaning:

U : apparent variability in the Tycho data; this may be due to duplicity, and the flag is only set if an indication of duplicity was also found, i.e. Field T49 = 'R' or 'S';

V : strong evidence of variability in the Tycho data; no correlation with position angle was evident, suggesting that the variability is intrinsic and not an apparent effect due to duplicity;

W : variability suspected in the Tycho data; this may be due to intrinsic variability since no correlation with position angle was evident. But no thorough investigation has been carried out to eliminate other reasons intrinsic to the Tycho measurements.

The number of entries in each of these categories is as follows: U = 15 795; V = 13 994; W = 75 730.

Tycho photometry has not yet been thoroughly used to investigate intrinsic stellar variability. The brightest 384 000 stars have been investigated to find stars having standard errors of the median magnitude exceeding those expected for constant stars with the same number of transits and the same magnitude (see Volume 4). Flags 'V' and 'W' can therefore only be used as an indication of an unexpectedly large scatter of the measurements, and do not necessarily mean that the object is intrinsically variable. The scatter may also be due to duplicity (see below) and disturbances by faint (undetected) stars crossing the star mapper slits at the same time as the Tycho star.

Correspondingly, the proportion of stars flagged 'V' and 'W' is larger in dense regions of the sky. On the other hand for a star satisfying the conditions $V_T \leq 9.5$ mag and $N_{\mathrm{photom}} \geq 80$ a 'blank' may be taken as an indication that the star was constant during the period of the Tycho observations.

A comparison with results from Hipparcos photometry indicates that the classification 'V' is mostly correct for stars brighter than $V_T \simeq 9.0$ mag, while for most stars fainter than $V_T \simeq 9.8$ mag 'V' may be a misleading indicator of variability.

Since duplicity may mimic variability in the Tycho observations, it is not always straightforward to disentangle these effects (see also Field T49). Investigations on variability and duplicity are separate processes, but the resulting lists of candidate variables or doubles do have a lot of stars in common. Stars have therefore been flagged as follows: if a star was found to be clearly double (Field T49 = 'D') then any suspected variability has been assumed to be caused by this duplicity, and thus Field T48 has been set to '␣' (blank).

Field T48 = 'U' was introduced to reflect those cases where it was not possible to decide between variability and duplicity. If a star was found to be a suspected double star (Field T49 = 'S') then Field T48 is set to 'U'. If a star was found to have an indication of variability and also a weak indication of duplicity, lower than the limit corresponding to Field T49 = 'S', Field T49 was set to 'R' and Field T48 was set to 'U'.

Field T49: Flag indicating unresolved duplicity status from Tycho data analysis

The flag has the following meaning:

D : duplicity (unresolved) was clearly indicated in about 8400 stars by Tycho data analysis (the published Tycho mean photometry is for the combined light, except for the astrometrically resolved components with Field T36 = 'D');

R : weak indication of duplicity, combined with indication of variability. This was found for some 11 500 stars which are then also flagged with Field T48 = 'U';

S : suspected duplicity from Tycho data analysis, although this duplicity cannot be regarded as certain. About 11 600 stars are assigned this flag, and 4500 of these also have Field T48 = 'U';

Y : an investigation was carried out on the Tycho data, but no indication of duplicity was found for about 450 000 stars;

Z : no investigation for duplicity was carried out on the Tycho data for about 570 000 stars mainly with $V_T > 10.5$ mag;

␣ : the Hipparcos stars (Field T42 = 'H').

The number of entries in each of these categories is as follows: D = 8441; R = 11 523; S = 11 639; Y = 449 209; Z = 571 219; ␣ = 6301.

Whenever an object observed by Tycho was clearly resolved into two stars, these were separated into two distinct catalogue entries, and the two stars assigned TYC1–3 designations as described under Field T1. Generally this was feasible for separations down to about 2 arcsec. However, it is also possible to detect doubles at smaller separations, down to about 0.8 arcsec (for bright stars even down to 0.6 arcsec). Such (unresolved) duplicity causes a perturbation (broadening) of the light curve produced by a transit of the object through the Tycho slits. A search for such perturbations was carried out in the Tycho data by two different methods, as described in Volume 4, Chapter 14. Field T49 represents the result of this search.

One of the methods was to search for a significant correlation between the estimated magnitude of the transit and the position angle of the measuring slit. This method was applied to about 510 000 stars with $V_T \leq 10.5$ mag. The other method was applied to the raw photon counts, and attempted to resolve the perturbed single peak into two peaks for every observation of a star. This method was applied to about 22 000 stars. The application of the two methods resulted in the flagging of about 20 000 stars with 'D' or 'S'.

Field T50: Flag indicating availability of epoch photometry for this object

The flag has the following meaning:

␣ : a blank field indicates that epoch photometry is not provided;

A : epoch photometry is given for these stars in the machine-readable Tycho Epoch Photometry Annex A, as made available on the ASCII CD-ROMs;

B : epoch photometry is not given in the Annex A but is given in a machine-readable data set, Annex B, made available at CDS, Strasbourg, containing also the stars from the Annex A.

The number of entries in each of these categories is as follows: A = 34 446; B = 447 107.

Tycho Epoch Photometry Annex B includes objects flagged 'A' as well as those flagged 'B', and therefore contains 34 446 + 447 107 = 481 553 entries.

Fields T51–57: Cross-identifications and Notes

In addition to the cross-identification to HIP/HIC (Field T31), the PPM, HD, and DM (BD, CoD, and CPD) identifiers are included.

These have been derived as a result of cross-identifications using the SIMBAD facility of the CDS, supplemented in the southern sky by direct use of the PPM Catalogue. As of April 1996, about half of the DM stars were not included in SIMBAD. A given DM identifier may be associated with more than one TYC entry because of the low accuracy of the DM positions. The cross-identification with the Hipparcos Catalogue identifier (HIP), combined with the component identifier if any, is unique, with the identity having been accepted if the TYC entry has a position within 1.0 arcsec of the Hipparcos Catalogue component at the epoch J1991.25. In 57 cases, however, a distance up to 2.0 arcsec was accepted when the identity appeared to be unambiguous and the position given by either catalogue was believed to be particularly uncertain. However, the astrometric quality of the HD and DM catalogues in particular is generally rather poor, and the resulting cross-identifications are therefore not always fully reliable or consistent.

For all other cross-identifications, the user is referred to the 'star names resolving facility' of SIMBAD, where the Tycho Catalogue identifier is included. Implicitly, the cross-identification to the variable star catalogues GCVS and NSV are given by the flag indicating known or suspected variability (see Field T47). The GCVS name and NSV number are specifically included in the *Celestia 2000* interrogation package, along with SAO Catalogue and HR Catalogue numbers and names of bright stars.

For HIP entries, reliability tests were performed, during the construction of the Hipparcos Input Catalogue, to check the coherence between the zones of the DM (BD, CoD, and CPD) numbers and the declination at the epoch of the catalogue (1855 for BD, 1875 for CoD and CPD), and also to check that the numbers increased with increasing right ascension at the epoch of the catalogue. Resulting corrections (from typing errors in the numbers or in the coordinates, originating from the source catalogue themselves or from an intermediate transcription, or confusion between the CoD and CPD identifiers) have been included.

Field T51: CCDM component identifier

The HIP number alone may be insufficient to identify uniquely the object in the Hipparcos Catalogue (if any) corresponding to the relevant Tycho Catalogue entry. This happens when the HIP entry has been resolved into two or more components, as listed in Part C of the Hipparcos Double and Multiple Systems Annex. These components are however uniquely identified by the HIP number combined with the component identifier in Field DC7 of the Double and Multiple Systems Annex. For such objects, Field T51 thus contains the CCDM component identifier taken from Field DC7.

There are 18 687 such entries in the Tycho Catalogue. The component identifier is normally a single letter: thus 'A' means that the TYC entry corresponds to the 'A' component of the HIP entry specified in Field T31. However, in about 6000 cases where two components of the Annex appear to correspond to one Tycho Catalogue entry, the two values from Field DC7 are combined, e.g. to 'AB'. In only three cases, indicated by 'TT', there were three components: ABC. Note that the components are given in lexical order (cf. Field H62 where, for example, 'AB' and 'BA' both occur).

The component identifiers originate from the CCDM catalogue (see Section 1.4), and therefore in principle refer to the systems identified by their CCDM numbers—which are not given in TYC. Such a system may have more than one HIP number, if the components are well separated, but a given HIP number can only have one CCDM number (given in Field H55 of the Hipparcos Catalogue). Consequently the HIP number plus the CCDM component identifier uniquely specifies a component.

Field T52: PPM identifier

The PPM (Catalogue of Positions and Proper Motions, U. Bastian & S. Röser 1994) is the largest source to date for high-precision proper motions, containing a very significant fraction (about 42 per cent) of the Tycho Catalogue stars.

Cross-identification was relatively straightforward, because of the positional precision of both the Tycho Catalogue and the PPM. Identity was accepted for stars in PPM with positions at J1991.25 having the closest TYC star within 2.5 arcsec separation in both coordinates. In the cases of 1700 single PPM stars, however, there were two TYC stars in this window, but none of them were accepted since the purpose was to give only reliable PPM proper motions. About 4600 of these 447 097 PPM proper motions disagreed significantly with the Tycho proper motion (as flagged by 'L' in Field T57).

The *Celestia 2000* interrogation package includes the PPM proper motions, which are, for a significant fraction of the Tycho stars, more precise than the Tycho proper motions. However, because of possible systematic and regional errors, and to retain the purely observational nature of the Hipparcos and Tycho Catalogues, the PPM proper motions are not included within the main mission data products.

Field T53: HD/HDE/HDEC identifier

Cross-identifications are given to 252 457 stars in the HD Catalogue, with numbers in the range 1 – 225 300 (A.J. Cannon & E.C. Pickering 1918–24, *Ann. Harvard Obs.*, 91–99), and its two extensions: HDE numbers in the range 225 301 – 272 150 (A.J. Cannon 1925–36, *Ann. Harvard Obs.*, 100), and HDEC numbers in the range 272 151 – 359 083 (A.J. Cannon & M. Walton Mayall 1949, *Ann. Harvard Obs.*, 112).

The number of cross-identifications in each of these categories is as follows: HD = 211732; HDE = 16540; HDEC = 24185.

Field T54: DM identifier (BD)

This field gives the DM identifier for 244 470 objects contained within the Bonner Durchmusterung (BD), with the format B±ZZ␣NNNNa (coded with leading zeros in ZZ where appropriate). Note that BD identifiers, unlike the CoD and CPD identifiers (Fields T55–56), may carry a lower-case suffix letter for additional stars, i.e. stars with suffix 'a', 'b', 'n', 'p' or 's': these stars were added to the BD Catalogue after the original numbering was made; such suffixes do not imply that the entry is a component of a double or multiple system (the suffixes 'b' and 'n' occur very seldom).

Field T55: DM identifier (CoD)

This field gives the DM identifier for 134 898 objects contained within the Cordoba Durchmusterung (CoD), with the format C±ZZ␣NNNNN.

Field T56: DM identifier (CPD)

This field gives the DM identifier for 154 604 objects contained within the Cape Durchmusterung (CPD), with the format P±ZZ␣NNNNN.

Field T57: Notes on dubious entries

If non-blank, this field has the following meaning (in decreasing sequence of priority):

J : disagreement with position or magnitude given in the Guide Star Catalog (GSC Version 1.1): in about 8000 cases the positions differ by more than 5 arcsec or 3σ, or the magnitudes differ by more than 1.5 mag. The B_T magnitude was used for the comparison if the GSC magnitude was derived from a blue plate, and the V_T magnitude in case of a visual plate. Tycho proper motions were used in the comparison of positions. Such flagged entries may be double stars, stars with extreme colours, galaxies, or planetary nebulae. However many are quite normal stars having erroneous positions, proper motions or magnitudes in the Tycho Catalogue or in the Guide Star Catalog;

K : dubious Tycho parallax: either (1) the parallax is significantly negative, less than $-4\sigma_\pi$; or (2) the difference, $|\Delta\pi|$, between the parallaxes from Hipparcos and Tycho is larger than $4\sigma_{\Delta\pi}$; or (3) a non-Hipparcos star has a Tycho parallax $> 40 + 4\sigma_\pi$ mas, which will in only very few cases be a real nearby star since nearly all nearby stars with parallaxes > 40 mas are Hipparcos stars;

L : dubious Tycho proper motion: a Tycho proper motion component, $\mu_\alpha \cos\delta$ or μ_δ, deviates $> 4\sigma_{\Delta\mu_{\rm comp}}$ from the PPM proper motion;

M : Tycho magnitude very uncertain: a subset of about 20 000 stars have a standard error larger than 0.3 mag in either B_T or V_T, or either of these magnitudes are missing. This may indicate variability, or may be due to an extreme colour index or to special observational circumstances, or the star may be very faint (see further details of the magnitudes described in the introduction to Fields T32–39).

Each of the astrometric criteria 'K' and 'L' identifies about 0.5 per cent of the catalogue entries as having large residuals, $> 4\sigma$. This is considered to be an acceptably small number of large residuals in astrometric observational data, since the tails of the distributions of such data rarely follow an ideal Gaussian distribution (for which a corresponding fraction of outliers of only 0.006 per cent would be predicted).

Under item 'K', condition (3) includes entries with large parallaxes not contained in the Hipparcos Catalogue, and is derived simply on the assumption that all such nearby objects are already contained within the Hipparcos Catalogue—an extreme, and presumably incorrect, assumption. The number of non-Hipparcos stars with Tycho Catalogue parallaxes larger than $40 + 4\sigma_\pi$ mas is 1245. This tail on the parallax error distribution will result in a number of erroneously large parallaxes—appropriate care will be required in using the Tycho parallaxes, together with other supplementary data, in the search for stars with real large parallaxes.

The number of entries in each of these categories is as follows: J = 7925; K = 5555; L = 4446; M = 18 791; total = 36 717. The number of entries corresponding to each of the criteria individually is as follows: J = 7925; K = 5763; L = 4653; M = 20 688. Thus the categories of stars satisfying the three first mainly astrometric criteria have little overlap. About 1400 stars satisfying 'J' would also satisfy 'M'.

Table 2.2.1. Summary of the machine-readable Tycho Catalogue format
(a) fields in common with the Hipparcos Catalogue

Field	Bytes	Format	Description
H0/T0	1–2	A1,X	Catalogue (H = Hipparcos, T = Tycho)
H1	3–15	6X,I6,X	Identifier (HIP number)
T1	„	I4,I6,I2,X	TYC1–3 (TYC number)
H2/T2	16–17	A1,X	Proximity flag
H3/T3	18–29	A11,X	Identifier RA, h m s (J1991.25)
H4/T4	30-41	A11,X	Identifier Dec, ± ° ′ ″ (J1991.25)
H5/T5	42–47	F5.2,X	V (Johnson) magnitude
H6	48–49	A1,X	Coarse variability flag
T6	„	1X,X	Blank for Tycho
H7/T7	50–51	A1,X	Source of magnitude identifier
H8/T8	52–64	F12.8,X	α, degrees (J1991.25)
H9/T9	65–77	F12.8,X	δ, degrees (J1991.25)
H10/T10	78–79	A1,X	Reference flag for astrometry
H11/T11	80–87	F7.2†,X	Trigonometric parallax (mas)
H12/T12	88–96	F8.2†,X	$\mu_{\alpha*} = \mu_\alpha \cos\delta$ (mas/yr)
H13/T13	97–105	F8.2†,X	μ_δ (mas/yr)
H14/T14	106–112	F6.2†,X	Standard error in $\alpha*$ at J1991.25 (mas)
H15/T15	113–119	F6.2†,X	Standard error in δ at J1991.25 (mas)
H16/T16	120–126	F6.2†,X	Standard error in π (mas)
H17/T17	127–133	F6.2†,X	Standard error in $\mu_{\alpha*}$ (mas/yr)
H18/T18	134–140	F6.2†,X	Standard error in μ_δ (mas/yr)
H19/T19	141–146	F5.2,X	Correlation, $\rho^{\delta}_{\alpha*}$
H20/T20	147–152	F5.2,X	Correlation, $\rho^{\pi}_{\alpha*}$
H21/T21	153–158	F5.2,X	Correlation, ρ^{π}_{δ}
H22/T22	159–164	F5.2,X	Correlation, $\rho^{\mu_{\alpha*}}_{\alpha*}$
H23/T23	165–170	F5.2,X	Correlation, $\rho^{\mu_{\alpha*}}_{\delta}$
H24/T24	171–176	F5.2,X	Correlation, $\rho^{\mu_{\alpha*}}_{\pi}$
H25/T25	177–182	F5.2,X	Correlation, $\rho^{\mu_{\delta}}_{\alpha*}$
H26/T26	183–188	F5.2,X	Correlation, $\rho^{\mu_{\delta}}_{\delta}$
H27/T27	189–194	F5.2,X	Correlation, $\rho^{\mu_{\delta}}_{\pi}$
H28/T28	195–200	F5.2,X	Correlation, $\rho^{\mu_{\delta}}_{\mu_{\alpha*}}$
H29	201–204	I3,X	Data points rejected (per cent)
T29	„	I3,X	Data points accepted, $N_{\rm astrom}$
H30/T30	205–210	F5.2,X	F2 (goodness-of-fit)
H31/T31	211-217	I6,X	HIP number
H32/T32	218–224	F6.3,X	B_T (mag)
H33/T33	225–230	F5.3,X	σ_{B_T} (mag)
H34/T34	231–237	F6.3,X	V_T (mag)
H35/T35	238–243	F5.3,X	σ_{V_T} (mag)
H36/T36	244–245	A1,X	Reference flag for B_T and V_T
H37/T37	246–252	F6.3,X	$B-V$ (mag)
H38/T38	253–258	F5.3,X	σ_{B-V} (mag)
H39	259–260	A1,X	Source of $B-V$
T39	„	1X,X	Blank for Tycho

† For these fields, the second decimal digit for the Tycho format is always blank

The Hipparcos and Tycho Catalogues are similar up to Field H39/T39; thereafter, the fields and their meanings are catalogue specific. Thus Tables 2.1.1(a) and 2.2.1(a) are identical. Due care must be taken in ensuring that blank fields are not interpreted as numerically zero.

Table 2.2.1. Summary of the machine-readable Tycho Catalogue format (cont.)
(b) Tycho specific catalogue data

Field	Bytes	Format	Description
T40	261–262	I1,X	Astrometric quality flag, Q
T41	263–267	F4.1,X	S/N ratio, F_S
T42	268–269	A1,X	Source of astrometric data
T43	270–273	I3,X	$N_{\rm photom}$
T44	274–279	F5.3,X	V_T scatter, s (mag)
T45	280–285	F5.2,X	Mag at max, V_T (15th percentile)
T46	286–291	F5.2,X	Mag at min, V_T (85th percentile)
T47	292–293	A1,X	Variability (from GCVS/NSV)
T48	294–295	A1,X	Variability (from Tycho)
T49	296–297	A1,X	Duplicity (from Tycho)
T50	298–299	A1,X	Flag (epoch data)
T51	300–302	A2,X	CCDM component identifier
T52	303–309	I6,X	PPM identifier
T53	310–316	I6,X	HD identifier
T54	317–327	A10,X	DM (BD) identifier
T55	328–338	A10,X	DM (CoD) identifier
T56	339–349	A10,X	DM (CPD) identifier
T57	350	A1	Notes